

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
22 April 2004 (22.04.2004)

PCT

(10) International Publication Number
WO 2004/034065 A1

(51) International Patent Classification⁷: **G01P 3/80**

(21) International Application Number:
PCT/US2003/031691

(22) International Filing Date: 6 October 2003 (06.10.2003)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/417,839 11 October 2002 (11.10.2002) US

(71) Applicant (*for all designated States except US*): THE TIMKEN COMPANY [US/US]; 1835 Dueber Avenue S.W., Canton, OH 44706 (US).

(72) Inventors; and

(75) Inventors/Applicants (*for US only*): AI, Xiaolan [US/US]; 4480 Noble Loon Street NW, Massillon, OH 44646 (US). VARONIS, Orestes, J. [US/US]; 1340 Irondale Circle NE, North Canton, OH 44720 (US). HWANG,

(74) Agent: BOOKS, Mark, E.; Polster, Lieder, Woodruff & Lucchesi, L.C., 12412 Powercourt Drive, Suite 200, St. Louis, MO 63131 (US).

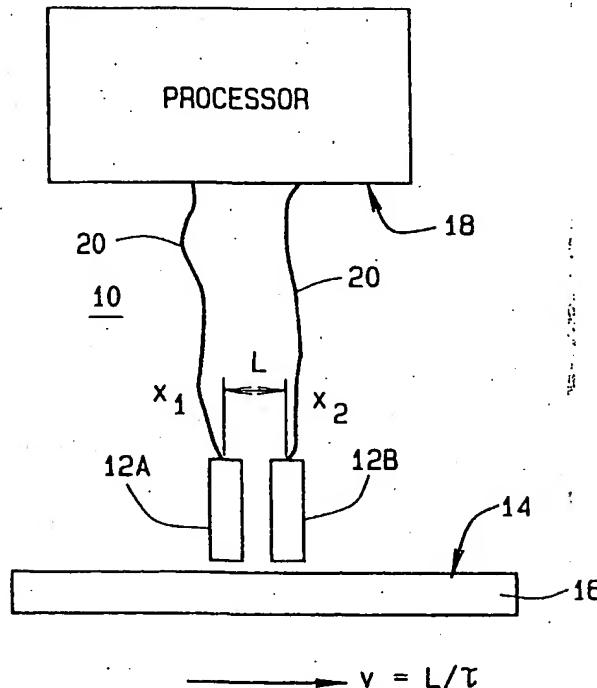
(81) Designated States (*national*): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States (*regional*): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PT, RO, SE, SI, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

[Continued on next page]

(54) Title: SPEED SENSING METHOD AND APPARATUS

$$y(\tau) = \int x_1(t+\tau) \cdot x_2(t) dt$$



(57) Abstract: A method and apparatus for measuring the speed of a target object passing a pair of sensor units (12) displaced apart by a predetermined distant L in the direction of motion of the target object (16). Passage of one or more features of the target object (16) past the first sensor unit (12A) results in the generation of a signal (x₁), and passage of the same feature of the target object (16) past the second sensor unit (12B) results in the generate of a second signal, (x₂). A signal processor (18) is configured to determine a mathematical correlation between signals (x₁) and (x₂), and an associated time delay (τ₀). The speed (v) of the target object (16) is calculated by the signal processor (18) as the ratio of the predetermined distance (L) to the time delay (τ₀).

WO 2004/034065 A1

BEST AVAILABLE COPY



Published:

- with international search report
- before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

3/px/14

SPEED SENSING METHOD AND APPARATUS

Cross-Reference to Related Applications

The present application is related to, and claims priority from, U.S. Provisional Patent Application No. 60/417,839 filed on October 11, 5 2002.

Technical Field

The present invention relates generally to speed sensors configured to monitor the speed of a moving body such as a shaft or axle, and in particular, to an improved speed sensing system utilizing a 10 pair of sensors each configured to detect random targets on a moving body, and a signal processor configured to measuring a phase shift between each target detection signals, the phase shift proportional to a speed of the target.

Background Art

15 Speed sensing plays an important role in monitoring, and thus controlling, machine operations. An accurate and reliable speed sensor is critical. Over the years numerous speed-sensing techniques and devices have been developed. Mechanical speedometers, electro-mechanical speed sensors, magnetic speed sensors, and optical speed 20 sensors are just a few examples. Most popular speed sensing systems often include a single sensor, an electronic control unit, and a target whose speed relative to the single sensor is measured.

Depending upon the type of speed being measured, i.e., linear or angular speed, and on the sensor technology that is employed, a target 25 may be constructed in a variety of ways and may take many different forms. Conventionally, speed sensing targets have been made from marked bars and toothed wheels, from multi-polar magnetic-strips and magnetic-rings, and from linear and angular bar-encoders. As the target moves relative to the sensor, a conventional sensor output signal takes 30 the form of a series of pulses, with the pulse frequency being proportional to the target wheel speed.

The resolution or accuracy of these conventional speed sensing systems depend heavily, among other factors, on the accuracy of the spacing between the teeth in a toothed target, the spacing of the magnetic poles in a magnetic target, and the spacing of the bars in a bar encoder. Thus, for a precision system, a target with high spacing accuracy is preferred.

However, the target manufacturing cost is proportional to the target spacing accuracy requirements, and it is not always economical to construct a large outer diameter angular target wheel or a long linear target with high spacing accuracy. Accordingly, it would be advantageous to introduce a speed sensing system which maintains a high degree of speed measurement accuracy without requiring the production and application of a precision speed sensing target.

Summary of the Invention

Briefly stated, the present invention sets forth a speed sensor system comprising a pair of sensing elements disposed in a directionally spaced relationship adjacent a surface of a moving object from which a speed measurement will be acquired. A target, having substantially random features is disposed on or beneath the surface, and is moved directionally past the pair of sensing elements by the movement of the object from which a speed measurement will be acquired. The pair of sensing elements are directionally spaced apart by a predetermined distance in the direction of the object's movement. Signals from each of the pair of sensing elements, generated by the passage of the target, are conveyed to a signal processor. The signal processor is configured to determine a phase shift between the generated signals which is inversely proportional to the speed at which the target passed the pair of sensor.

As a method for measuring a target speed, the present invention includes the steps of observing at a first point, a plurality of random features of said target, generating a first signal representative of said observations at said first point, observing at a second point displaced

from said first point in a direction of motion of said target, said plurality of random features of said target, generating a second signal representative of said observations at said second point, and calculating a phase shift between said first signal and said second signal, said phase shift inversely proportional to a speed of said target.

5. The foregoing and other objects, features, and advantages of the invention as well as presently preferred embodiments thereof will become more apparent from the reading of the following description in connection with the accompanying drawings.

10 Brief Description of Drawings

In the accompanying drawings which form part of the specification:

Figure 1A is a simplified diagrammatic view of one embodiment of a speed sensor system of the present invention in relation to a linearly moving object;

15 Figure 1B is a perspective view of the speed sensor system of Fig. 1A in relation to a rotationally moving object;

Figure 2A graphically illustrates sample eddy-current sensor signals received from a pair of adjacent speed sensors units of the 20 present invention;

Figure 2B graphically represents a cross correlation function between the two signals shown in Figure 2A;

Figure 3A illustrates a first speed sensor configuration relative to the direction of motion of a target object;

25 Figure 3B illustrates a second speed sensor configuration relative to the direction of motion of a target object;

Figure 3C illustrates a third speed sensor configuration relative to the direction of motion of a target object; and

30 Figure 4 compares results in measuring angular speed from a speed sensor system of the present invention using a pair of eddy current sensors together with a toothless target wheel against the results from a conventional variable reluctance (VR) speed sensor system.

Corresponding reference numerals indicate corresponding parts throughout the several figures of the drawings.

Best Mode for Carrying Out the Invention

The following detailed description illustrates the invention by way of example and not by way of limitation. The description clearly enables one skilled in the art to make and use the invention, describes several embodiments, adaptations, variations, alternatives, and uses of the invention, including what is presently believed to be the best mode of carrying out the invention.

Turning to Figures 1A and 1B, the basic components of a speed sensor system 10 of the present invention are shown. A pair of speed sensor units 12A and 12B are disposed in a spaced relationship adjacent a toothless target surface 14 of a moving object 16, for example, the circumferential surface of a bearing race as shown in Figure 1B. Preferably, the speed sensor units 12A and 12B are spaced apart by a predetermined distance L between the speed sensor unit centers, aligned with the direction of motion of the target surface 14, shown by the arrow in Figure 1A. The sensor units 12A and 12B are operatively coupled to a signal processing unit 18. Preferably, as shown in Figure 1A, the sensor units 12A and 12B are directly coupled to the signal processing unit 18 by electrically conductive wires 20 configured to communicate respective signals x_1 and x_2 from the sensor units 12A and 12B to the signal processing unit 18. However, those of ordinary skill in the art will recognize that a variety of components may be utilized to couple the sensor units 12A and 12B to the signal processing unit 18, including wireless transmission components.

The operating principles of the current invention are based on generating and analyzing two mathematically correlated signals x_1 and x_2 from the pair of sensor units 12A and 12B in the speed sensor system 10. By detecting the phase shift between corresponding points in each of the two signals x_1 and x_2 , a time delay can be determined. The phase variation in signals is solely related to the speed of motion. The speed of

motion can be calculated as the ratio of the distance L between the sensor units 12A and 12B, and the determined time delay.

For accuracy considerations, it is highly desirable to use random signals, each preferably having a high frequency content. To this end, a target surface 14 with random or near random topographical features (roughness) is employed as target to produce randomly variable signals. With certain types of sensor units 12A and 12B, such as eddy current sensors, the randomness of the signals x_1 and x_2 can be enriched by subsurface material property variations.

The first sensing unit 12A and the second sensing unit 12B are configured to be substantially sensitive to surface and/or subsurface features of the target surface 14, and are functionally similar in that each sensor unit 12A, 12B produces identical signals or substantially similar signals when passing over the same surface or subsurface features on the target surface 14. Alternative sensor units 12 may include optical sensors sensitive to optical variations on the target surface 14.

As the target surface 14 moves relative to the speed sensor system 10, the first sensing unit 12A and the second sensing unit 12B each generate signals, such as exemplified in Figure 2A, at an identical sampling rate f that is substantially higher than the signal variation rate, allowing the speed sensing system 10 to resolve high frequency surface features even at the highest target speeds.

In general, a correlation exists between the first signal $x_1=[x_{11}, x_{12}, x_{13}, \dots, x_{1j}, \dots, x_{1n}]$ generated by the first sensing unit 12A and the second signal $x_2=[x_{21}, x_{22}, x_{23}, \dots, x_{2j}, \dots, x_{2n}]$ generated by the second sensing unit 12B in response to the passage of surface or subsurface features on the target surface 14, where n represents the sample size (number of data points in a sample). There is, however, a time delay of

$$\tau_0 = \frac{m}{f}$$
 between the first signal x_1 and second signal x_2 where m

represents the number of shifted data points. The direction of the signal

shifting corresponds the direction of the motion of the target surface 14 relative to the sensor units 12A and 12B.

Thus, a cross correlation function $y(\tau)$ between the signals x_1 and x_2 may be defined by the equation:

$$5 \quad y(\tau) = \int x_1(t + \tau) \cdot x_2(t) dt \quad \text{Equation (1)}$$

which reaches a maximum value when $\tau = \tau_0$.

The time delay τ_0 can be determined by finding the maximum value of the cross correlation function of the signals x_1 and x_2 . That is:

$$\tau_0 = \psi(y_{\max}) \quad \text{Equation (2)}$$

10 where ψ is an inverse function to the cross correlation function $y(\tau)$ defined in Equation (1).

During operation, signal processor 18 receives and processes signals x_1 and x_2 . The incoming signals x_1 and x_2 are initially processed to remove any direct current (DC) components, resulting in a pair of signals each having zero-mean such as shown in Figure 2A. The signal processor 18 further performs the cross correlation analysis of the two signals, preferably using a Fast Fourier Transform (FFT) based algorithm for fast computation. Next, the signal processor 18 determines the time delay τ_0 between the two signals by calculating the maximum value for the cross correlation function $y(\tau)$ defined in Equation (1). Finally, the speed of motion v for the target surface 14 past the sensor units 12A and 12B is computed by the signal processor 18 as:

$$v = \frac{L}{\tau_0} \quad \text{Equation (3)}$$

25 Optionally, the signal processor 18 may be configured to compute a relative position of the target surface 14 by integrating the computed speed v with respect to time.

Returning to Figure 2A, the signals x_1 and x_2 illustrated graphically are representative of signals from a pair of independent eddy

current speed sensor units 12A and 12B positioned 0.788 inches apart along the circumferential direction of motion for a rotating target surface 14, such as shown in Figure 1B. For a sampling rate of approximately 48 kHz, the resulting sample size is 3700 data points for a single 5 revolution of the target surface 14. In the graph shown in Figure 2A, the horizontal axis represents sample sequencing and vertical axis is the strength of the signals in volts. The cross correlation function of signals x_1 and x_2 , illustrated in Figure 2B, identifies a maximum value at data point 4036 that corresponds to a shifting of 336 data points ($4036-10 3700=336$). The corresponding time delay between the first signal x_1 and second signal x_2 is $\tau_0 = 336/48000 = 0.007$ sec. The surface speed of the target 14 is then $v = 0.788/0.007 = 112.6$ in/sec. The direction of motion is determined by the direction of signal shifting.

Based on the selected sensor technology, the signal processor 15 18 and sensor units 12A, 12B could be integrated into a single unit 20, such as shown in Figure 1B using modern ASIC fabrication techniques with Digital Signal Processing (DSP) computation ability.

To ensure a good correlation between the two signals x_1 and x_2 under less than ideal installation and/or application conditions, 20 differential sensing combinations of speed sensor units 12 may optionally be used. In this case one sensor combination may contain more than two speed sensing units 12. A comparison of signals from each of the speed sensor units 12 comprising the differential sensing combinations permits removal or cancellation of signal components 25 common to all sensing units 12, such as noise or interference, which are present at each speed sensor unit location. These common signal components usually carry no information with respect to signal phase shifting.

Figures 3A through 3C illustrate three differential sensing 30 combinations and the positioning of the associated speed sensing units 12 in relationship to the direction of motion of the target surface 14. In Figure 3A, a first sensor combination 100 contains four speed sensor

units 12A – 12 D positioned at the corners of a rectangle to form two differential sensing pairs. The first differential sensing pair is formed by speed sensor units 12A and 12C, and the second differential sensing pair is formed by speed sensor units 12B and 12D. In the first differential 5 sensing pair, speed sensor units 12A and 12C are separated by a center distance W perpendicular to the direction of motion. In the second differential sensing pair, speed sensor units 12B and 12D are similarly separated by the center distance W, perpendicular to the direction of motion. Each differential sensing pair is spaced apart by a 10 distance L substantially in the direction of motion.

Figure 3B illustrates an alternate arrangement for a sensing system 200 wherein the differential sensing pairs 12A, 12C and 12B, 12D are disposed at the corners of a parallelogram, i.e., where the center lines between speed sensor units 12A and 12C and between 15 speed sensor units 12B and 12D are not perpendicular to the center line defined by the position of speed sensor units 12A and 12B. The included angle α between speed sensor units 12A, 12C and speed sensor units 12A, 12B is set equal to the included angle β between speed sensor units 12B, 12D and speed sensor units 12A, 12B. That is 20 $\alpha = \beta$, such that the placement of the speed sensor units 12A – 12D defines a parallelogram having two sides parallel to the direction of motion of the target surface 14. In general, α and β could each vary from 0 to 360 degrees.

Figure 3C shows an alternate arrangement for a sensing system 25 300 similar to that shown in Figure 3A, but where the first pair of differential sensing units 12 A, 12C and the second pair of differential sensing units 12B, 12D are disposed in two different sensor housings, and hence are spaced apart by a distance $L' > L$. As is shown in Figure 3A, the centerline between the centers of sensing elements 12A and 30 12B substantially aligns with the direction of motion of the target surface 14. Correspondingly, the center line that connects the centers of the

sensing elements 12C and 12D is also substantially aligned with the direction of motion. The center lines connecting the centers of the first pair of differential sensing units 12A, 12C is parallel with the center line that connects the centers of the second pair of differential sensing units 5 12B, 12D, and substantially perpendicular to the direction of motion for the target surface 14.

The current invention is not confined to any specific type of speed sensors units. However, the speed sensor units 12 are preferably eddy current sensors capable of generating signal variations induced both by 10 topographical features on the target surface 14 and by subsurface material property changes in the target object 16. This allows the sensing system to be used not only for rough target surfaces 14 but also for smooth target surfaces 14 where the signal variation is induced primarily by subsurface material property changes rather than by surface 15 topographical features.

Figure 4 graphically illustrates the validity of the sensing system 10 and techniques of the present invention in measuring angular speed using a pair of eddy current speed sensor units 12A, 12B and a toothless target object 16. The graph of Figure 4 plots the angular speed 20 of the target object 16 as measured by the sensing system 10 of the present invention versus the angular speed of the target object 16 as measured by a conventional variable reluctance (VR) speed sensor system, illustrating a close correlation between the two sensor systems.

It should be understood that the sensing system 10 and 25 techniques of the present invention are applicable to a host of applications such as for use in bearing application, and particularly in bearing applications wherein the target surface 14 is a bearing seal.

In view of the above, it will be seen that the several objects of the invention are achieved and other advantageous results are obtained. As 30 various changes could be made in the above constructions without departing from the scope of the invention, it is intended that all matter

-10-

contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

Claims

1. A speed sensing system for measuring the speed of a target object, comprising:
 - a first speed sensor unit operatively disposed adjacent a surface of said target object, said first speed sensor unit configured to generate a first signal responsive to the passage of at least one feature of said target object;
 - a second speed sensor unit operatively disposed adjacent a surface of said target object and displaced at a predetermined distance from said first speed sensor unit substantially in a direction of motion of the target object, said second speed sensor unit configured to generate a second signal responsive to the passage of said at least one feature of said target object; and
 - a signal processor configured to receive said first and second signals, said signal processor further configured to determine a phase shift between said generated signals, said phase shift inversely proportional to a speed of said target object.
2. The speed sensing system of Claim 1 further including:
 - a third speed sensor unit operatively disposed adjacent a surface of said target object, said third speed sensor unit configured to generate a third signal responsive to the passage of at least one feature of said target object;
 - a fourth speed sensor unit operatively disposed adjacent a surface of said target object and displaced at a predetermined distance from said third speed sensor unit substantially in a direction of motion of the target object, said fourth speed sensor unit configured to generate a fourth signal responsive to the passage of said at least one feature of said target object; and

wherein said signal processor is further configured to receive said third and fourth signals, and to utilize said third and fourth signals to cancel signal components common to said first, second, third, and fourth signals.

-12-

3. The speed sensing system of Claim 2 wherein said signal processor is further configured to provide differential signals between the first and third signals, and between the second and fourth signals, and said signal processor is further configured to determine a phase shift between said third and fourth generated signals, said phase shift inversely proportional to a speed of said target object.

4. The speed sensing system of Claim 2 wherein said first and third speed sensing units define a first differential sensing pair;

10 wherein said second and fourth speed sensing units define a second differential sensing pair; and

wherein said first and second differential sensing pairs are spaced apart by a predetermined distance parallel to said direction of motion of the target object.

5. The speed sensing system of Claim 1 wherein said first and second speed sensing units are eddy current sensors.

6. The speed sensing system of Claim 1 wherein said first and second speed sensing units are optical sensors.

7. The speed sensing system of Claim 1 wherein said signal processor is configured to process said generated signals such that said generated signals have a zero signal mean.

8. The speed sensing system of Claim 1 wherein said signal processor is configured to determine a cross correlation function between said generated signals, said cross correlation function defined by:

$$25 \quad y(\tau) = \int x_1(t + \tau) \cdot x_2(t) dt$$

where x_1 is said first generated signal;

x_2 is said second generated signal;

t is a signal time; and

τ is a time delay between said generated signals.

-13-

9. The speed sensing system of Claim 8 wherein said phase shift is associated with a maximum value for said cross correlation function; and wherein said signal processor is further configured to determine a maximum value for said cross correlation function;

5 wherein a speed v of said target object is determined from:

$$v = \frac{L}{\tau_0}$$

where L is said predetermined distance; and

10 τ_0 is a time delay corresponding to said determined maximum value for said cross correlation function.

10 10. The speed sensing system of Claim 1 wherein said first speed sensor unit and said second speed sensor unit are disposed within a common housing.

11. The speed sensing system of Claim 1 wherein said at least one target feature is a random surface feature of the target object.

15 12. The speed sensing system of Claim 1 wherein said at least one target feature is a random subsurface feature of the target object.

13. The speed sensing system of Claim 1 where each of said first and second speed sensing units has an identical sampling rate; and wherein said identical sampling rate is substantially greater than a 20 signal variation rate for said first and second speed sensing units.

14. A method for speed measurement of a target object, comprising the steps of:

observing at a first point, a passage of at least one feature of the target object;

25 generating a first signal responsive to said passage of said at least one feature at said first point;

observing at a second point, displaced at a predetermined distance from said first point in a direction of motion of said target object, said passage of said at least one feature of the target object;

-14-

generating a second signal responsive to said passage of said at least one feature at said second point;

calculating a phase shift between said first signal and said second signal, said phase shift inversely proportional to a speed of said
5 target object.

15. The method of Claim 14 for speed measurement of an object wherein said phase shift is associated with a maximum value of a cross correlation function between said first and second generated signals, and wherein said step of calculating further includes the step of
10 calculating said maximum value of said cross correlation function between said first and second generated signals, said cross correlation function defined by:

$$y(\tau) = \int x_1(t + \tau) \cdot x_2(t) dt$$

where x_1 is said first generated signal;

15 x_2 is said second generated signal;

t is a signal time; and

τ is a time delay between said generated signals.

16. The method of Claim 15 for speed measurement of an object, further including the step of determining a speed v of said target
20 object from:

$$v = \frac{L}{\tau_0}$$

where L is said predetermined distance;

and τ_0 is a time delay corresponding to said determined maximum value for said cross correlation function.

25 17. The method of Claim 14 for speed measurement of an object further including the steps of :

observing at one additional point, a passage of an additional feature of the target object;

-15-

generating at least one additional signal responsive to said passage of said additional feature at said third point;

utilizing said at least one additional signal to cancel common elements present in each of said generated signals.

5 18. A method for determining a relative position of a target object, comprising the steps of:

observing at a first point, a passage of at least one feature of the target object;

10 generating a first signal responsive to said passage of said at least one feature at said first point;

observing at a second point, displaced at a predetermined distance from said first point in a direction of motion of said target object, said passage of said at least one feature of the target object;

15 generating a second signal responsive to said passage of said at least one feature at said second point;

calculating a speed of said target object, said calculated speed inversely proportional to a phase shift between said first signal and said second signal; and

20 determining a relative position of the target object from said calculated speed.

19. The method of Claim 18 for determining a relative position of a target object wherein said determining step includes the step of integrating said calculated speed with respect to time.

25 20. The method of Claim 18 for determining a relative position of a target object wherein said phase shift is associated with a maximum value of a cross correlation function between said first and second generated signals, and wherein said step of calculating further includes the step of calculating said maximum value of said cross correlation function between said first and second generated signals, said cross 30 correlation function defined by:

$$y(\tau) = \int x_1(t + \tau) \cdot x_2(t) dt$$

-16-

where x_1 is said first generated signal;

x_2 is said second generated signal;

t is a signal time; and

τ is a time delay between said generated signals.

5 21. The method of Claim 20 for determining a relative position
of a target object wherein said speed v of said target object is calculated
from:

$$v = \frac{L}{\tau_0}$$

where L is said predetermined distance; and

10 τ_0 is a time delay corresponding to said determined maximum
value for said cross correlation function.

1/3

$$y(\tau) = \int x_1(t+\tau) \cdot x_2(t) dt$$

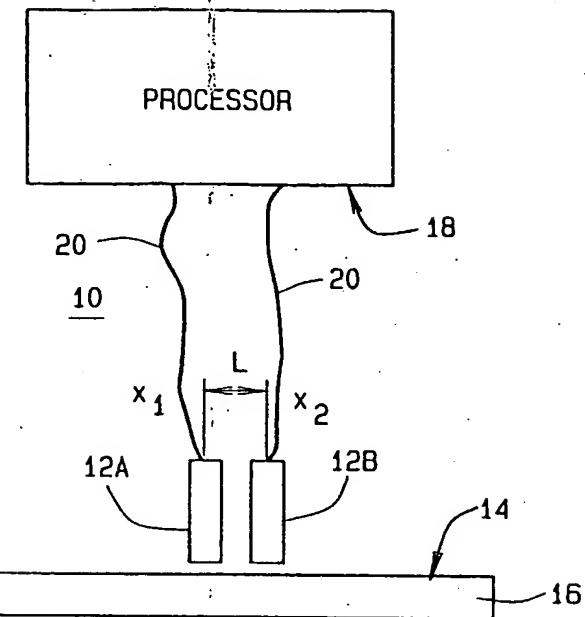
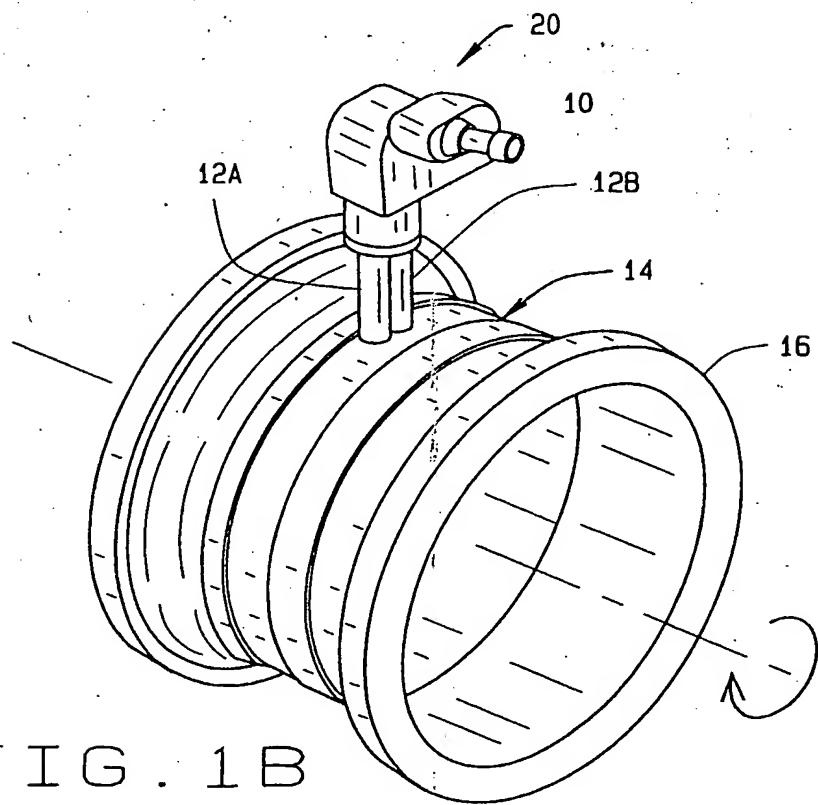
FIG. 1A $\rightarrow v = L/\tau$ 

FIG. 1B

Digitized April 27, 2005

THIS PAGE BLANK (USPTO)

10/531098

WO 2004/034065

CT/US2003/031601

2/3

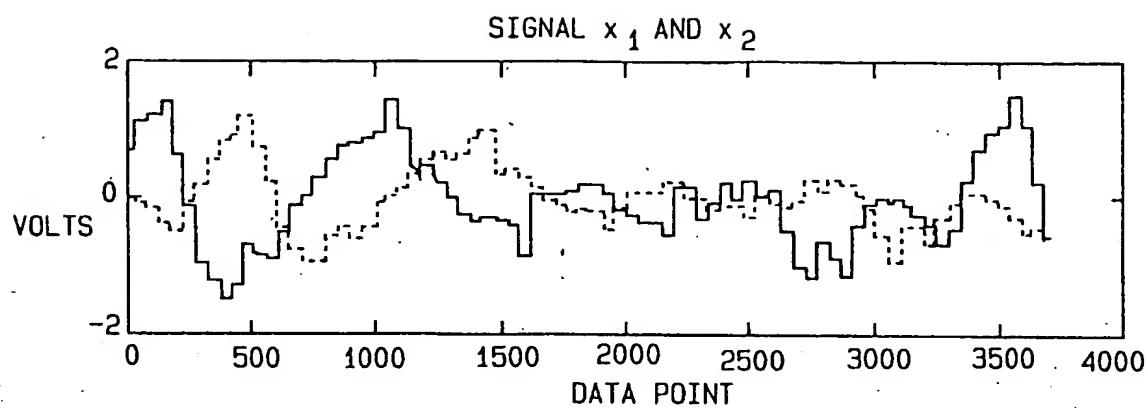


FIG. 2A

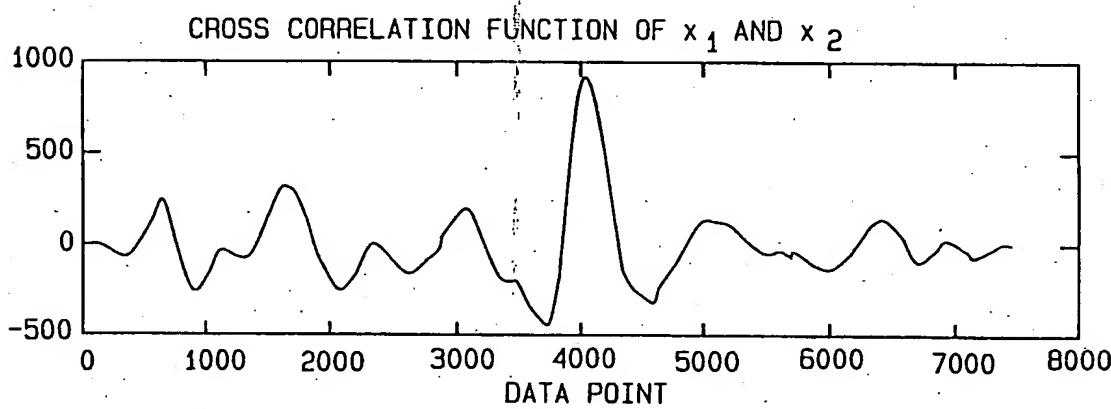


FIG. 2B

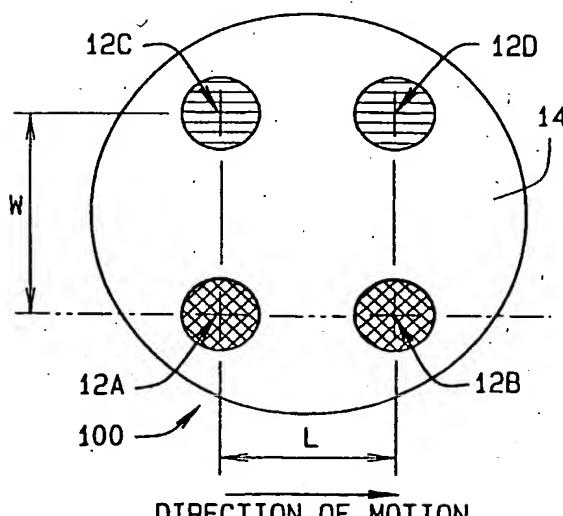


FIG. 3A

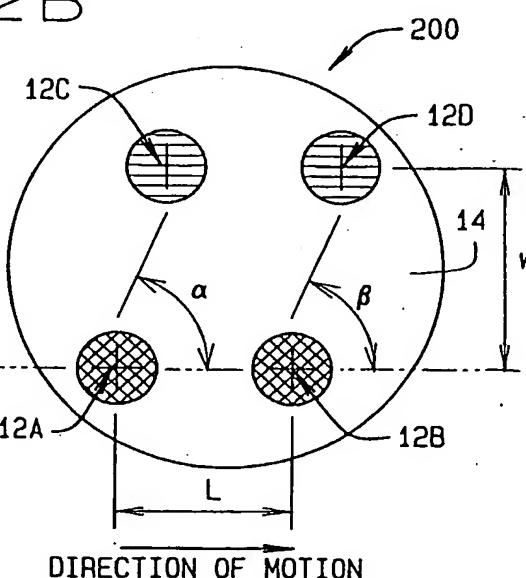


FIG. 3B

JG12 Rec'd PCT/PTC 07 APR 2005

THIS PAGE BLANK (USPTO)

3/3

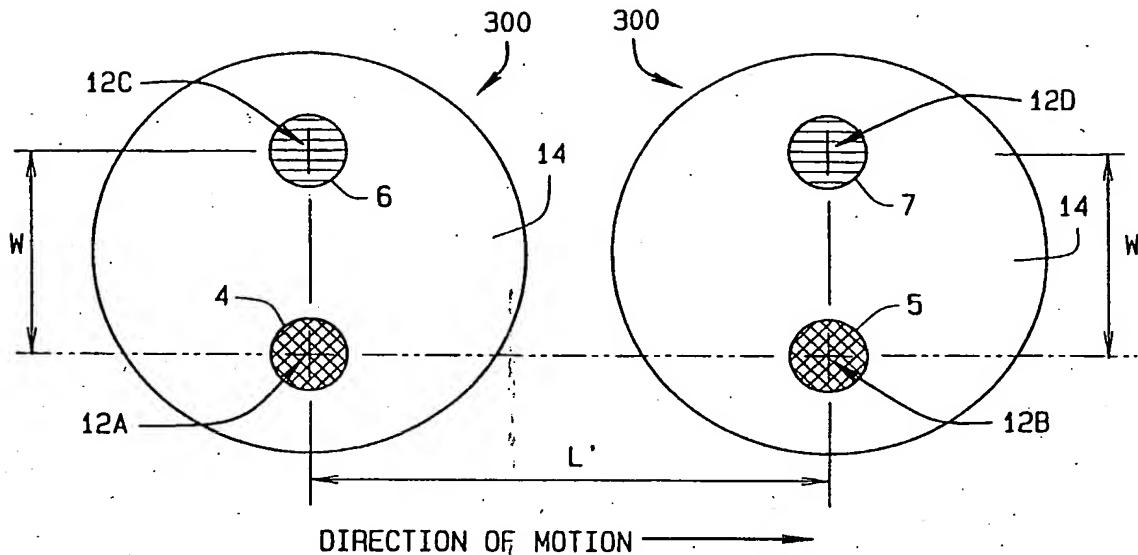


FIG. 3C

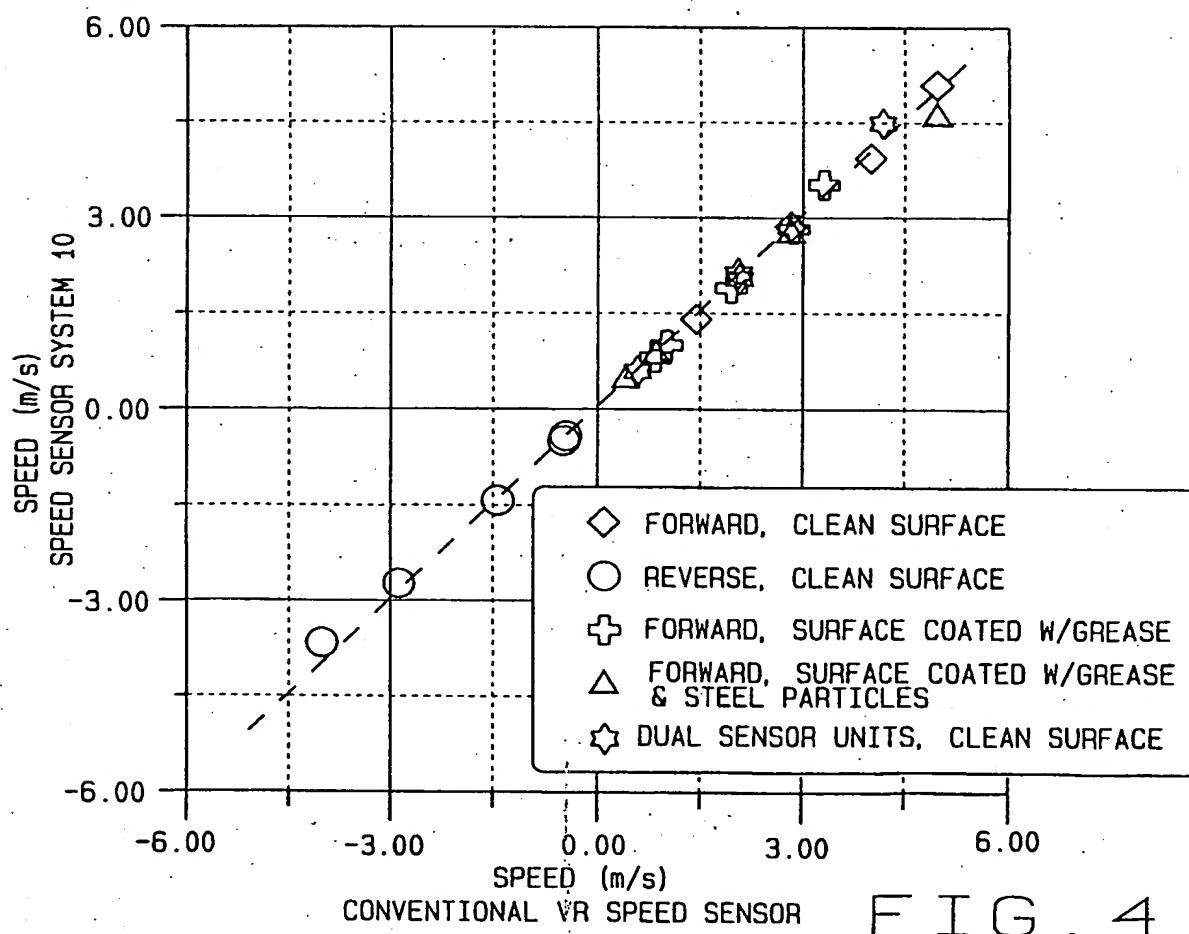


FIG. 4

JC12 Rec'd PCT/PTC 07 APR 2005

THIS PAGE BLANK (USPTO)

PATENT COOPERATION TREATY

PCT

INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference TIMK 8502WO	FOR FURTHER ACTION see Notification of Transmittal of International Search Report (Form PCT/ISA/220) as well as, where applicable, item 5 below.	
International application No. PCT/US 03/31601	International filing date (day/month/year) 06/10/2003	(Earliest) Priority Date (day/month/year) 11/10/2002
Applicant THE TIMKEN COMPANY		

This International Search Report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This International Search Report consists of a total of 4 sheets.

It is also accompanied by a copy of each prior art document cited in this report.

1. Basis of the report

a. With regard to the language, the international search was carried out on the basis of the international application in the language in which it was filed, unless otherwise indicated under this item.

the international search was carried out on the basis of a translation of the international application furnished to this Authority (Rule 23.1(b)).

b. With regard to any nucleotide and/or amino acid sequence disclosed in the international application, the international search was carried out on the basis of the sequence listing :

contained in the international application in written form.

filed together with the international application in computer readable form.

furnished subsequently to this Authority in written form.

furnished subsequently to this Authority in computer readable form.

the statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.

the statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished

2. Certain claims were found unsearchable (See Box I).

3. Unity of invention is lacking (see Box II).

4. With regard to the title,

the text is approved as submitted by the applicant.

the text has been established by this Authority to read as follows:

5. With regard to the abstract,

the text is approved as submitted by the applicant.

the text has been established, according to Rule 38.2(b), by this Authority as it appears in Box III. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority.

6. The figure of the drawings to be published with the abstract is Figure No.

as suggested by the applicant.

because the applicant failed to suggest a figure.

because this figure better characterizes the invention.

1A

None of the figures.

THIS PAGE BLANK (USPTO)

INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 03/31601

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G01P3/80

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G01P

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 85 05187 A (STIFTELSEN INST MIKROVAGS) 21 November 1985 (1985-11-21) page 2, line 19 - line 25 page 3, line 8 - line 14 page 4, line 5 - line 8 figures 1,2	1,6-11, 13-21 2-4
X	US 2001/046042 A1 (PUTTKE BERNHARD ET AL) 29 November 2001 (2001-11-29) paragraph '0002! paragraphs '0031!, '0032! paragraphs '0088!, '0089! figures 1,2,10	1,5-21
		-/-

 Further documents are listed in the continuation of box C. Patent family members are listed in annex.

* Special categories of cited documents :

- *A* document defining the general state of the art which is not considered to be of particular relevance
- *E* earlier document but published on or after the international filing date
- *L* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- *O* document referring to an oral disclosure, use, exhibition or other means
- *P* document published prior to the international filing date but later than the priority date claimed

- *T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- *X* document of particular relevance; the claimed Invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- *Y* document of particular relevance; the claimed Invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
- *&* document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
20 February 2004	26/02/2004

Name and mailing address of the ISA
European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,
Fax: (+31-70) 340-3016

Authorized officer

Reto, D

THIS PAGE BLANK (USPTO)

INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 03/31601

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	PATENT ABSTRACTS OF JAPAN vol. 018, no. 253 (P-1737), 13 May 1994 (1994-05-13) -& JP 06 034647 A (HAMAMATSU PHOTONICS KK), 10 February 1994 (1994-02-10) abstract ---	2-4
A	US 5 652 509 A (WEIS MANFRED) 29 July 1997 (1997-07-29) column 4, line 29 - line 35 column 7, line 8 - line 10 figures 2,4 ---	3,7
A	US 5 825 177 A (FINNESTAD ASKELL ET AL) 20 October 1998 (1998-10-20) column 4, line 1 - line 3 figure 1A ---	10
A	DE 40 14 756 A (CENITH SYSTEMS GMBH & CO KG) 21 November 1991 (1991-11-21) column 3, line 42 - line 51; figure 3A ---	1,5,8,9, 11-21

THIS PAGE BLANK (USPTO)

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/03/31601

Patent document cited in search report		Publication date		Patent family member(s)		Publication date
WO 8505187	A	21-11-1985	SE AT DE EP WO	440150 B 41061 T 3568492 D1 0180633 A1 8505187 A1		15-07-1985 15-03-1989 06-04-1989 14-05-1986 21-11-1985
US 2001046042	A1	29-11-2001	DE EP	10013512 A1 1136826 A2		11-10-2001 26-09-2001
JP 06034647	A	10-02-1994		NONE		
US 5652509	A	29-07-1997	DE CH IT JP	4434234 A1 693618 A5 MI951958 A1 8105909 A		28-03-1996 14-11-2003 25-03-1996 23-04-1996
US 5825177	A	20-10-1998	SE AT AU DE DE EP JP SE WO	515008 C2 204386 T 2941095 A 69522237 D1 69522237 T2 0797779 A1 10506182 T 9402350 A 9601431 A1		28-05-2001 15-09-2001 25-01-1996 20-09-2001 05-09-2002 01-10-1997 16-06-1998 05-01-1996 18-01-1996
DE 4014756	A	21-11-1991	DE	4014756 A1		21-11-1991

THIS PAGE BLANK (USPTO)

**This Page is Inserted by IFW Indexing and Scanning
Operations and is not part of the Official Record**

BEST AVAILABLE IMAGES

Defective images within this document are accurate representations of the original documents submitted by the applicant.

Defects in the images include but are not limited to the items checked:

- BLACK BORDERS**
- IMAGE CUT OFF AT TOP, BOTTOM OR SIDES**
- FADED TEXT OR DRAWING**
- BLURRED OR ILLEGIBLE TEXT OR DRAWING**
- SKEWED/SLANTED IMAGES**
- COLOR OR BLACK AND WHITE PHOTOGRAPHS**
- GRAY SCALE DOCUMENTS**
- LINES OR MARKS ON ORIGINAL DOCUMENT**
- REFERENCE(S) OR EXHIBIT(S) SUBMITTED ARE POOR QUALITY**
- OTHER: _____**

IMAGES ARE BEST AVAILABLE COPY.

As rescanning these documents will not correct the image problems checked, please do not report these problems to the IFW Image Problem Mailbox.

THIS PAGE BLANK (USPTO)